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CURRENT FLYING AND HANDLING QUALITIES SIMULATIONS IN AFRL/VA

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There has been renewed interest in recent years by the Air Force and collaborative partners in industry, academia, and other government agencies in conducting real-time, pilot-in-the-loop, motion-based simulations exploring Flying and Handling Qualities (FHQ) of future aircraft concepts. This field of study, prematurely declared by a few as a "sunset science", has returned to relevance and importance as modern methods of control law design are used to maximize performance of highly unconventional air vehicle designs.

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CURRENT FLYING AND HANDLING QUALITIES SIMULATIONS IN AFRL/VA

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Abstract

There has been renewed interest in recent years by the Air Force and collaborative partners in industry, academia, and other government agencies in conducting real-time, pilot-in-the-loop, motion-based simulations exploring Flying and Handling Qualities (FHQ) of future aircraft concepts. This field of study, prematurely declared by a few as a "sunset science", has returned to relevance and importance as modern methods of control law design are used to maximize performance of highly unconventional air vehicle designs. Pilot-in-the-loop, motion simulation remains a vital method of demonstrating, proving concepts and defining Flying and Handling Qualities of these aircraft and later, to reduce the risk of flight test as a design matures out of the conceptual stage. This paper presents information about three recent real-time, Flying and Handling Qualities simulations in AFRL/VACD's motion-base Large Amplitude Multimode Aerospace Research Simulator ("LAMARS"): the Boeing-AFRL, "Super-STOL" Advanced Theater Transport (ATT), an "Advanced STOL-Transport", and the USAF Test Pilot School and Air Force Institute of Technology's "HAVE PREVENT" Pilot Induced Oscillation (PIO) simulation. Following an overview of AFRL/VACD's FHQ simulation environment, aircraft missions and descriptions are presented and followed by the piloted evaluation plans and summarized results of each of the three simulations. Though engagement and mission level simulations may have eclipsed FHQ simulation in priority, FHQ simulation in AFRL/VA continues to hold an important niche.

Introduction and Overview of AFRL/VACD's Realtime Flying and Handling Qualities Simulation Environment

Flying and Handling Qualities (FHQ) motion-base simulation development and evaluation in AFRL/VACD is now more highly collaborative and faster paced. Development teams are often composed of Air Force, members of academia, and contractors working at distant locations up until the time of simulation testing. This has presented some issues in simulation development: there is often no common development and simulation environment between team members, reliable but older "legacy" code is in constant reuse at many locations, and simulation development today follows more aggressive time schedules. AFRL/VACD has addressed these issues and has managed to satisfy customers and partners within aggressive time constraints by maintaining a flexible "quick-response" real-time motion-base Flying and Handling Qualities simulation environment shown in Figure 1. There are three software development paths in AFRL / VACD for achieving this: 1) the Matlab /Simulink and Realtime Workshop 2) the real-time-GENESIS, and 3) the "DSIX", Windows-based PC real-time simulation capabilities.

Matlab/Simulink/Realtime Workshop

The increasing use of Matlab and Simulink with RealTime Workshop (RTW) for design and simulation by much of academia and industry is paralleled in AFRL/VACD, where the latest versions are maintained. In AFRL/VACD, non-realtime simulations are constructed in Matlab and Simulink and then coded into C++ using Real Time Workshop. For example, the recent Cooperative Research and Development effort between AFRL/VA and Boeing Tankers and Transports, the Advanced Theater Transport (ATT) seen in Figure 2 and described later in this paper, saw all control system design and non-realtime simulation buildup done on Matlab and Simulink by Boeing design engineers. Progressively complex versions of the entire Simulink simulation of the ATT including checkcases were then emailed directly to AFRL/VACD simulation engineers at Wright-Patterson, loaded into Simulink and checkcases validated within minutes. Coding the simulation into C++ modules via Real Time Workshop was performed and quickly followed by integration into VACD's Silicon Graphics realtime simulation executive for pilot-in-the-loop, motion base simulation in the AFRL LAMARS simulator*.

* In addition to the simulation development path just described, one can also export a Matlab/Simulink simulation directly into the

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GENESIS Realtime Simulation Environment
The General Environment for the Simulation of Integrated Systems, or "GENESIS"[2] is an extremely versatile non-realtime and realtime simulation and analysis package developed for the Air Force in the early 1990s by Northrop Grumman. Though designed originally for air vehicle applications, GENESIS can be host to any linear or non-linear dynamic system and comes with a complete library of self-initializing common dynamic elements, which can be readily linearized. GENESIS also includes a database management system to maintain tabular data files and perform interpolated data lookups. GENESIS is written entirely in Fortran 77 and is still the tool of choice when FHQ simulations in VACD make use of large amounts of "legacy" Fortran code, though modules written in "C" and "C++" can easily be linked into the GENESIS executable program. In it's non-realtime mode, GENESIS has a powerful debugger and many useful interactive user commands, including the capability to run Monte Carlo simulations and to vary parameters "on-the-fly". In it's realtime mode, GENESIS receives executive-level commands (e.g. "reset", "trim", etc.) from VACD's Silicon Graphics realtime executive and can be released back to batch simulation and analysis at any time. Data can then be output for analysis in user-selectable formats including Matlab, MATRIXX, or GNUPLOT.

Bihrle Applied Research (BAR) "DSIX"
AFRL/VACD has begun a commitment to a low-cost, Windows-based, PC simulation environment starting with the integration and use of "DSIX [3,4]". "DSIX", a product of Bihrle Applied Research, was created under the Air Force SBIR program for the desktop simulation and comprehensive analysis of unpiloted combat air vehicle stability, control, and flying qualities. DSIX is written in C++, is object-based, and has since evolved into a highly versatile tool for rapid vehicle synthesis, control law design, and realtime simulation including realtime and post-simulation data analysis. DSIX has many useful extensions, including the ability to import aerodynamic data in many formats as well as the abilty to directly import or export Matlab and Simulink models. It is also straightforward to interface one or multiple, networked DSIX machines to the user's existing simulation hardware and software environment, which AFRL/VACD and others have done with success.

Windows-Based DSIX realtime simulation environment described in this paper.

Three Recent Flying and Handling Qualities Simulations at AFRL/VACD

The versatile simulation environment just introduced has been put to steady use in three recent Flying and Handling Qualities (FHQ) simulations in AFRL/VACD using the LAMARS motion simulator. These simulations, the 1) "Super STOL", AFRL-Boeing Advanced Theater Transport, or "ATT" simulation, the 2) "Advanced STOL Transport" simulation and the 3) VISTA F-16 "HAVE PREVENT" PIO simulation are now described in more detail, including the air vehicle description, evaluation plan and an overview level of simulation results.

AFRL - Boeing Advanced Theater Transport Simulation

Aircraft Mission
This recent Flying and Handling Qualities simulation was the culmination of a Cooperative Research and Development Agreement between AFRL and Boeing Tankers and Transports (Long Beach) to explore technical issues and overall feasibility of a large Super-Short Takeoff and Landing (SSTOL) theater transport. The mission of the SSTOL ATT transport concept is to provide the Air Force with the capability to lift heavy, outsized loads from points of debarkation to numerous, unimproved and constantly changing forward supply points. The ATT is envisioned to have "at least the same payload, range, volume, weight and cruise speed of the C-130J" and should be capable of taking off and landing-fully loaded-over obstacles and rolling out to a complete stop in 800 feet[†] or less in high density altitude atmospheric conditions. While it may be reminiscent of the VTOL XC-142 and similar aircraft of an earlier era, the ATT concept is not capable of hovering flight, as it is not necessary for the intended mission.

Aircraft Description
Figure 2 shows key features of the very unconventional SSTOL Advanced Theater Transport design. Most noticeable is the lack of a vertical tail (to save structural weight and reduce drag during cruise flight) and four 30 foot-diameter, 8-bladed rotors driven by turbine engines hung from a tiltable wing. The wing is swept forward 25 degrees at 40% span to achieve favorable movement of the aerodynamic center with changing flight condition and to generate

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[†] Working definition of SSTOL performance

more effective control moments, as well as to get desired ground clearance when the wing is tilted at angles up to 45 degrees. The slat and flap system relies heavily on ADVINT [7,8] technology to enable use of simple but high-rate flaps to achieve sufficient pitch and roll control moments at low dynamic pressures. Additional pitch, roll, and yaw control moments are provided by pitch and yaw cyclic capability on each rotor as well as by differential power between port and starboard engine pairs. All control effectors (including rotors and differential power) are integrated by the flight control system so that the pilot is able to fly the aircraft using conventional airplane controls. "Total engine power" is commanded by the pilot using a single throttle as if the airplane has a single engine. When configured for SSTOL flight as depicted in Figure 2, the 250,000# ATT concept can fly as slow as 64 KIAS, touch down over a 50' obstacle and rollout in under 800 feet.

ATT Simulation Objectives & Evaluation Plan

The Boeing / AFRL ATT Simulation using the LAMARS had multiple objectives, but the three most important ones were: 1) to demonstrate that desired Super-STOL landing and rollout performance was achieved with the ATT design concept, 2) to explore flying and handling qualities and other issues unique to SSTOL aircraft and 3) to assess ATT control power requirements. Additional simulation objectives were to: validate the modern control design methodology-Dynamic Inversion with Control Allocation [5,6] -used to achieve stability, control, and flying and handling qualities characteristics with the most effective use of all available control effectors, and to obtain insightful opinions and recommendations from pilots on any simulation features needing improvement. Of great importance to AFRL/VA were pilot comments on the fidelity and usefulness of LAMARS motion cues for this particular simulation.

ATT Evaluation Plan

All objectives were demonstrated in the successful execution of an extensive evaluation plan developed by Boeing specifically for the ATT in the final approach and landing phase of flight. The complete listing of possible evaluation conditions is shown in Table 1. Three qualified pilots were each asked to practice and perform seven approach and landing tasks (the left-most column in Table 1) in the ATT. For each task, ATT attributes included up to two levels of control power (actuator bandwidth and rate limits), up to two CG loading conditions and up to three levels of control augmentation (with respect to the bare airframe dynamics) to meet flying qualtities requirements and to reject disturbances. Furthermore, for a given set of attributes pilots were asked to perform the tasks with and without the autopilot at three possible levels of turbulence and wind shear.

Desired and Adequate levels of pilot performance were defined for both approach and landing phases of each task. For the approach phase, pilot performance in tracking airspeed, glideslope and localizer were measured, recorded, and scored against desired and adequate values. In the landing and rollout phase, lateral and longitudinal displacement of the main gear from a visual touchdown marker on the runway, main gear sinkrate, aircraft pitch and roll attitude at touchdown and rollout distance were the performance metrics measured and scored. Desired or adequate pilot performance in each parameter was reviewed with the pilot at the completion of each evaluation run and then followed by the completion of a general pilot comment card and completion of Cooper-Harper [9] and Pilot Induced Oscillation (PIO) [10] ratings when applicable.

ATT Simulation Results Overview [11]

A full two weeks was invested in ATT simulation calibration and final checkout with a highly qualified evaluation pilot. Checkout focused on tuning LAMARS motion cues‡, adjusting the LAMARS hydraulic control loader to achieve desired ATT –specific control inceptor dynamics, and ensuring exact alignment and correlation between Out-the Window (OTW) and HUD displays and the ATT vehicle model. Following simulation checkout, 37 of the most demanding, highest-priority test conditions§, chosen apriori by Boeing from Table 1, were repeated at least three times by three qualified test pilots. Analysis of data, including pilot ratings, comments, video recordings of HUD and pilot-eye view visual data as well as relevant aircraft vehicle and flight control system parameters revealed that all simulation test objectives were met, namely:

1) Pilots were able to consistently achieve at least adequate performance in approach

‡ Adjusting appropriate gains to match LAMARS accelerometer outputs to simulation model

§ A "test condition" is a unique combination of attribute values listed in each row of Table 1.

and landing tasks. They were able to maneuver the ATT and "Put the aircraft on the runway where they wanted it" then rollout in the very short distances desired. Furthermore they were able to touchdown at realistic rates (8-12fps) of sink.

2) Flying and Handling qualities of the ATT in the demanding approach and landing phase, while needing improvement, were generally good. Pitch, speed, flight path control and pitch dynamics were well behaved as were roll control and roll dynamics. Additional issues unique to this type of SSTOL aircraft were uncovered and are discussed further in this paper.
3) A realistic analysis of control power requirements for future design purposes was performed and generated specific measures-of-merit indexed to pilot tasks [11]. Furthermore, the flight control scheme used for ATT, Dynamic Inversion (DI) with Control Allocation[5,6], was an appropriate control law methodology for this complex and highly-coupled air vehicle concept. Most uncommanded and undesirable modes were suppressed and the control laws could be changed easily to achieve desired FHQ criteria.
4) Secondary objectives were also met: It was clear from pilot comments that well-tuned LAMARS motion cues were an aid to pilot judgment especially for this aircraft in power approach and landing tasks. LAMARS cues were 1:1 in many cases and aided the pilot's control strategy by providing accurate feedback.

There were also considerable lessons learned to apply to follow-on ATT simulations[12] and iterations of the ATT design process and for SSTOL aircraft in general:

1) Average Cooper Harper ratings were in the 4-5 range due to a variety of factors contributing to pilot workload. Chief among these were: yaw control laws which needed more augmentation to dampen dutch-roll oscillations, increasing the sensitivity of the single integrated throttle, and addressing-via enhanced flight control system design- a pitch coupling problem during power changes which was more severe than anticipated due to the tilt-wing configuration during landing approach.

2) There was insufficient pitch control power to rotate the aircraft to climb attitude during performance of the go-around task with a forward CG setting[¶]. A possible cause is thought to be the negative lift increment from the trim stabilator (Figure 2), causing an examination of alternate ways to achieve trim.

3) Typical rates of sink experienced by the main gear at touchdown were in the 8-12 fps range as mentioned previously. However, an appreciable number of test runs experienced main gear touchdown sink rates of 14-16 fps when pilots were especially concerned about minimizing rollout distance. This points to the possible need for such a SSTOL aircraft to have a very robust gear combined with an automatic device such as NASA's "height damper"[13] to keep the landing gear and payload inside safe limits at touchdown.

4) An extremely important lesson learned was the demonstrated need for improved Heads-down and Heads-up pilot displays highly tailored for large SSTOL aircraft like the ATT. The challenge is to enable the ATT pilot, sitting far ahead of the main gear and, in the landing attitude, with a partial obstruction of the desired touchdown area by the aircraft nose, to achieve the best ATT landing and rollout performance possible by precisely placing the main gear on the desired touchdown marker within gear structural limits. To meet this challenge in the LAMARS simulation required the addition of static HUD symbology and an additional runway visual aimpoint placed a calculated distance ahead of the desired main gear touchdown zone. For a consistent glide path and approach speed, the static symbology was adequate; by aiming the HUD symbol at the visual aimpoint on the runway and keeping a sink-rate indicator within bounds, pilots would "automatically" steer the main gear to the desired touchdown zone. (It is realized that in the "real world", HUD and synthetic runway aimpoint symbology will be dynamic functions of speed, pitch and flight path angle.) It is noted that pilots participating in the ATT simulation opined that their

¶ This flight condition is not listed in Table 1

performance may have been adversely affected by the HUD symbology available[11].

The AFRL/VA-Boeing ATT simulation effort in the LAMARS was a notable success and was followed closely by a second motion-base simulation of the ATT at NASA-Ames by Boeing and NASA personnel. Some of the shortcomings highlighted by the AFRL/VA simulation (e.g. pilot displays) were addressed further, and the interested reader is strongly encouraged to review the NASA-Ames results[12].

AFRL-Northrop-Grumman Advanced STOL Transport Simulation

Aircraft Mission:

The Advanced STOL Transport, represented in Figure 3, is an Intra-Theater, survivable, STOL jet transport concept. Following a STOL or conventional takeoff, the mission profile may include a high-altitude cruise segment and possible in-flight refueling, followed by a high subsonic, low-altitude and survivable ingress, and finally a rapid, semi-automatic aircraft reconfiguration and transition to STOL flight just prior to reaching the final approach segment. The pilot captures and maintains critical final-approach and landing parameters of the custom GPS approach displayed in the HUD, completes the approach, lands the 170,000# aircraft over a 50ft. obstacle and rolls to a stop in under 3000 ft.

Advanced STOL Transport Simulation Objectives and Evaluation Plan

Critical objectives of the Advanced STOL Transport simulation in AFRL/VA using the LAMARS motion simulator were to:
1) Demonstrate and quantify effects of new, practical, and more affordable aerodynamic technologies enabling STOL performance,
2) Verify STOL performance targets, and
3) Explore Flying and Handling Qualities and single-pilot workload issues during STOL Approach, Landing and Rollout, STOL Takeoff, and during STOL missed-approaches followed by reconfiguration to cruise flight. Completing these objectives successfully reduced the risk to interested stakeholders in pursuing the STOL technologies further.

Evaluation Plan

While more specific details and simulation results are beyond the scope of this paper, the general evaluation plan was completed by three pilots with appropriate background in similar aircraft and covered the following test conditions:

1) STOL Approach- Pilots completed a total of 86 STOL approach conditions over obstructions, including landing and rollout to a complete stop, at four final approach speeds and three glideslope angles. Additional independent variables included atmospheric turbulence and crosswinds, high-density altitude field conditions, day and night operation in reduced visibility, aircraft empenage size, and aircraft weight. Finally, some of the 86 approach conditions were initiated with altitude and lateral offsets from the final approach course, with the pilot instructed to aggressively get back on glideslope and localizer at predetermined heights above the runway. In all STOL approach conditions the pilot's task was to 1) capture the localizer, glideslope, and ideal airspeed, 2) land over the obstacle in the desired touchdown zone within safe gear parameters followed by 3) a rollout in under 3000' using the braking methods available.

2) STOL Takeoff- Pilots also completed 32 STOL takeoff conditions. Takeoffs were conducted over obstacles at three rotation speeds and at different aircraft weights, and included headwinds, tailwinds, turbulence, standard and sea-level and "high and hot" field conditions.

Data and Results:

As in the case of the Boeing ATT, analysis of pilot ratings, comments, video recordings of HUD and pilot-eye view visual data as well as relevant aircraft vehicle, propulsion, and flight control system state parameters revealed that all simulation test objectives were met, demonstrating that the technology on display is feasible and achieves STOL design objectives with a tolerable pilot workload.

VISTA F-16 "HAVE PREVENT" Pilot Induced Oscillation (PIO) Simulation

Aircraft Mission:

The Variable Stability Inflight Simulator Test Aircraft (VISTA), shown in Figure 4 is a specially modified NF-16D which can, because it has a reprogrammable flight control computer, simulate characteristics of other aircraft[14].
The VISTA Variable Stability System (VSS) Flight Control Computer can be reprogrammed in-flight to vary bare airframe dynamics, such as short period frequencies and damping, to model stable or unstable dynamics of another aircraft as well as the ability of the model flight control system to

compensate. Control surface commands necessary to simulate model behavior are computed by the VSS and are sent to special high-rate actuators made possible by a special high-flowrate hydraulic system. The simulated aircraft is flown by the "evaluation pilot" (EP) sitting in the front cockpit using a programmable-feel sidestick (or centerstick) and throttle. The rear-seat, or Safety Pilot (SP), has conventional F-16 controls and engages the VSS just prior to handing off aircraft control to the evaluation pilot. The safety pilot can take control at any time or can wait for an automatic safety-trip of the VSS by the "VISTA Integrity Monitor" (VIM) to do so. Because it's an in-flight simulator, a major advantage of the VISTA over ground-based simulators is it's 1:1 motion cues. Being a real aircraft however, it involves considerable expense to operate. An accurate motion-base simulation of VISTA is useful for initial project results, to work out problems, and to plan and rehearse VISTA sorties just prior to flight test.

VISTA F-16 "HAVE PREVENT" PIO Simulation Objectives and Evaluation Plan

The overall objective is to maintain a real-time piloted LAMARS motion simulation of the VISTA F-16 to support the Air Force Institute of Technology (AFIT) and the USAF Test Pilot School (TPS) at Edwards AFB in student studies of Pilot Induced Oscillation (PIO) phenomena. These PIO studies are usually part of a thesis project done to fulfill the AFIT-TPS Master of Science curriculum, and culminate in test flights aboard the VISTA F-16. For the year 2002, the AFIT-TPS student project, titled "HAVE PREVENT", was to study and compare the ability of two filters-the "Derivative Switching" PIO filter designed by AFIT[15] and the "Feedback with Bypass" filter[16] designed by SAAB- to prevent the occurance of PIO due to actuator rate limiting while preserving aircraft flying and handling qualities. Specific objectives of the PIO simulation at AFRL/VACD were to allow AFIT-TPS students to evaluate their 2002 project with motion simulation just prior to flight test by 1) practicing and rehearsing every test sortie in their flight test plan, 2) by exploring test conditions deemed too hazardous for flight test, 3) by verifying that the most useful data was recorded for later analysis, and by 4) allowing each group member to practice their specific flight test duties and to meet critical time constraints. A goal of the AFRL engineers was to gather additional pilot opinions on the fidelity and quality of the LAMARS PIO simulation with motion as a valuable pre-flight test tool.

Evaluation Plan

It was the job of AFRL/VACD to construct and integrate all simulation software and hardware components (Figure 1) and run the VISTA F-16 LAMARS motion simulation, while student test pilots and flight test engineers from the USAF TPS were responsible for the planning and execution of all LAMARS simulation and follow-on VISTA flight testing[17]. The "HAVE PREVENT" study project was divided into three steps:

Step One consisted of desktop modeling and simulation using Matlab/Simulink. The complete study space for comprehensively examining the two PIO filters in the next two steps was defined and examined during this phase to obtain predicted results. Figure 5 describes the complete study space consisting of three filter states, each evaluated against four bare airframe models[#] at four actuator rate limits, for a total of 48 distinct test points.

Step Two was the realtime piloted VISTA F-16 LAMARS motion base simulation at AFRL/VACD. In Step Two, the study space defined in Step One (now grouped and scheduled into 14 "flight test sorties" in an actual flight test plan) was covered exactly as it was to be performed in follow-on flight tests. Three test pilot candidates evaluated each of the 48 possible test points (implied in Figure 5) in the three-phase process shown in Figure 6. Test points were randomly ordered by flight test engineers so that pilots were never aware of the aircraft case, actuator rate limit setting or filter configuration. After each run, pilots completed PIO and Cooper Harper Ratings, which were used by flight test engineers to apply the Air Force Flight Test Center Five Point General Purpose Scale shown at the bottom of Figure 6. The results can be seen in Figures 7 through 10, which, taken together, identify which PIO filter was the "winner".

Step Three was the execution of the flight test plan, which consisted of 13 sorties in the VISTA F-16 (Figure 4) during October 2002.

VISTA F-16 "HAVE PREVENT" PIO LAMARS Simulation and Flight Test Results Overview

Complete results of the VISTA F-16 PIO "HAVE PREVENT" study can be found in reference 17.

[#] It is the characteristics of the four bare airframe models that the VISTA F-16 is able to simulate with its Variable Stability System flight control computer.

Results for the least stable bare-airframe cases (cases 'C' and 'D') from sorties flown first in the LAMARS simulator and then in VISTA flight tests are repeated below in Figures 7 through 10 for comparison. Figures 7 and 8, which present a comparison of the filters' ability to maintain baseline FHQ in the presence of actuator rate limiting, reveal close correlation between LAMARS simulator predictions and actual flight test results. It is very clear that, as predicted in simulation, the Feedback With Bypass (FWB) filter was superior to the Derivative Switching (DS) filter** in preserving aircraft handling qualities when rate limiting was present. The same assessment can be made when comparing Figures 9 and 10. Again, there is very close agreement between LAMARS simulator predictions and flight test on the ability of the DS and FWB filters to prevent or at least to bound PIO. It is clear once again that, as predicted in the LAMARS simulation, the FWB filter outperformed the DS filter by a wide margin in flight test. As to the quality and utility of the LAMARS motion simulation of the VISTA F-16, it was the unanimous opinion of the TPS team that the LAMARS PIO simulation of the VISTA F-16 achieved all the objectives set for ground based simulation: 1) It made valid predictions about flight test results, 2) It gave realistic and helpful motion cues to pilots, 3) It allowed very realistic flight test rehearsal for the whole team and as a result, saved considerable flight test time.

3.0 Summary

Far from being a "sunset science", Flying and Handling Qualities research using a versatile software design and simulation environment centered on the LAMARS motion simulator will continue to maintain a valuable niche in AFRL/VA for the foreseeable future. This paper has presented three recent and highly successful examples of collaborative FHQ research between AFRL/VA and industry as well as other Air Force agencies such as AFIT and the USAF Test Pilot School. FHQ research in AFRL/VA continues with additional projects in the study of PIO as well as in new "mobility aircraft" studies and even in unmanned air vehicles.

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** An improved version of the DS filter remains to be evaluated. (See: Ref 17, Sect VI)

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TABLES AND FIGURES

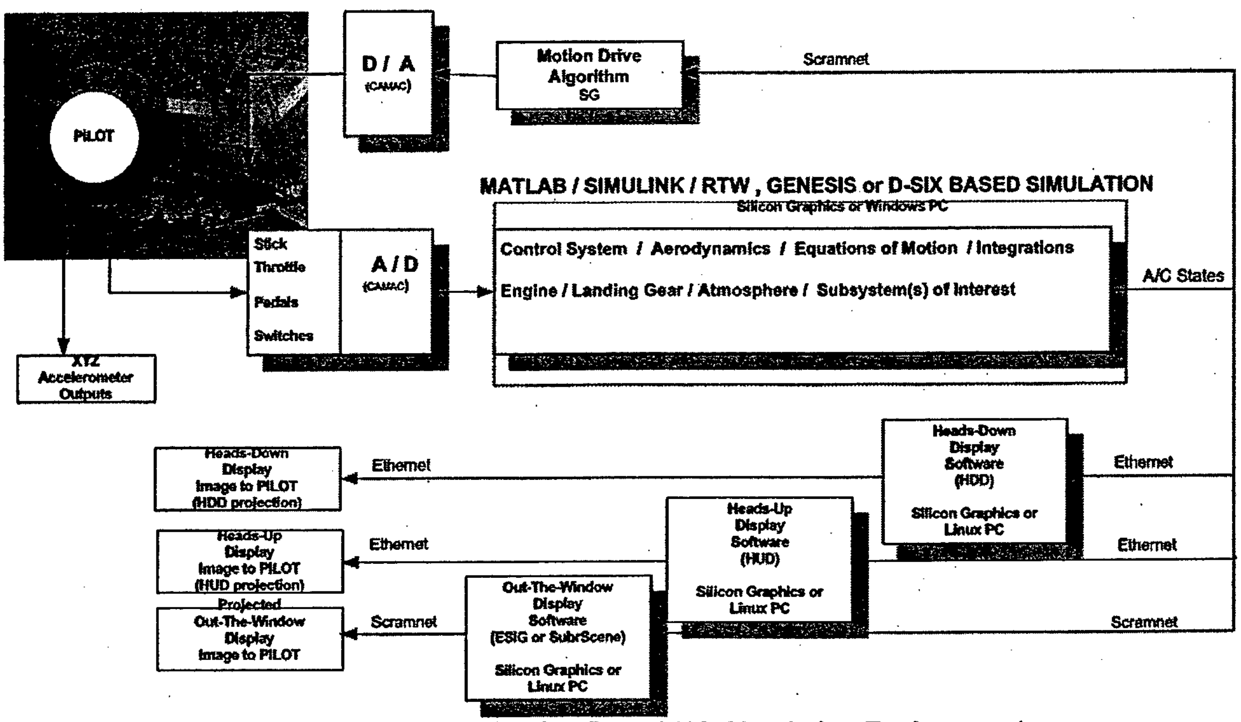

Figure 1: AFRL/VACD Motion Base FHQ Simulation Environment

Table 1: ATT Experimental Test Matrix

Evaluation Task	Control Power Level	CG Position	FCS Augmentation Level	AutoThrottle	Turbulence Level
Vertical Offset App/Lnd	Baseline, Increased	Fwd, Aft	Low, Med, High	ON, OFF	L, M, S
Lateral Offset App/Lnd	Baseline, Increased	Fwd, Aft	Low, Med, High	ON, OFF	L, M, S
Slalom App/Lnd	Baseline, Increased	Fwd, Aft	Low, Med	ON, OFF	L, M, S
30 kt X-Wind App/Lnd	Baseline, Increased	Fwd, Aft	Low, Med, High	ON, OFF	L, M, S
Airspeed Capture App/Lnd	Baseline	Aft	Low, Med	ON, OFF	L, M, S
Go-Around	Baseline, Increased	Aft	Med	ON, OFF	L, M, S
App/Lnd with Wind Shear	Baseline	Aft	Med	ON, OFF	

Notes:
App/Lnd – Approach and Landing
Wing-tilt angle fixed at °20 All Cases

Turbulence:
(L) Light, (M) Moderate, (S) Severe

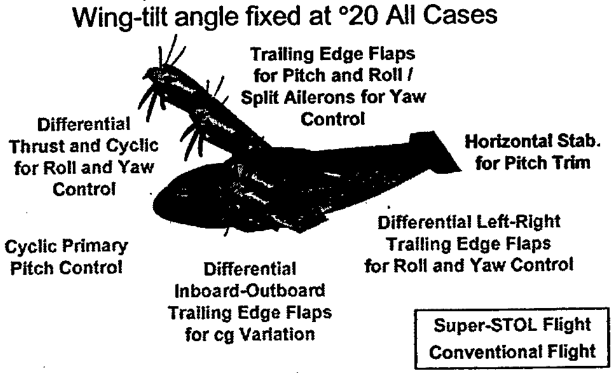

Figure 2: Boeing/AFRL SSTOL ATT

Figure 3: A Representative Configuration of the Advanced STOL Transport

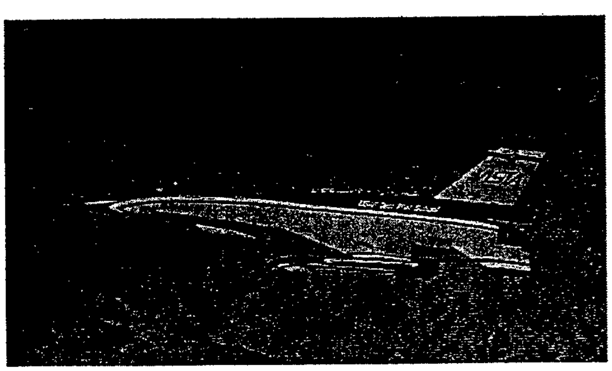

Figure 4: VISTA NF-16D In-Flight Simulator

Two Filters + No Filter...	...Evaluated Against Four Bare Airframe Responses...	...At Four Actuator Rate Limits:
▪ SAAB Feedback with Bypass (FWB) ▪ AFIT Derivative Switching (DS) ▪ No Filter	▪ Case A – Very Stable ▪ Case B – Stable ▪ Case C – Slightly Unstable ▪ Case D – Very Unstable	▪ 15 deg/sec ▪ 30 deg/sec ▪ 45 deg/sec ▪ 60 deg/sec

Figure 5: PIO "HAVE PREVENT" Simulation Test Points

Phase 1: Gentle maneuvering, pitch captures.
Goal: Pilots evaluate the basic "feel" of the aircraft

Phase 2: Aggressive tracking of HUD generated discrete and sum-of-sines pitch tracking tasks; attempt to meet desired or adequate criteria.

Goal: Gather PIO ratings

Phase 3: Operational evaluation tracking a target aircraft; attempt to meet desired or adequate criteria.

Goal: Gather Cooper Harper Ratings

...Performance of current configuration compared to baseline "No Filter" configuration using five point AFFTC scale and ratings from Phases 2 and 3:

1) Much Better
2) Better
3) About the Same
4) Worse
5) Much Worse

Figure 6: Three Phases of a PIO "HAVE PREVENT" Test Point Evaluation

Aircraft Case	Rate Limit	FWB vs No-Filter	DS vs No-Filter	FWB vs DS	Best Performer
C	All	Better	Much Worse	Much Better	FWB
	60 deg/sec	Better	Worse	Better	FWB
	45 deg/sec	About the Same	Much Worse	Better	FWB
	30 deg/sec	Better	Much Worse	Better	FWB
D	All	Much Better	About the Same	Much Better	FWB

Figure 7: Summary of Simulation Results for Handling Qualities

Aircraft Case	Rate Limit	FWB vs No-Filter	DS vs No-Filter	FWB vs DS	Best Performer
C	All	Better	Worse	Much Better	FWB
	45 deg/sec	Better	About the Same	Much Better	FWB
	30 deg/sec	About the Same	Worse	Better	FWB
	15 deg/sec	Better	Worse	Better	FWB
D	All	Much Better	About the Same	Much Better	FWB

Figure 8: Summary of Flight Test Results for Handling Qualities

Aircraft Case	Rate Limit	FWB vs No-Filter	DS vs No-Filter	FWB vs DS	Best Performer
C	All	Much Better	About the Same	Much Better	FWB
	60 deg/sec	Better	About the Same	Better	FWB
	45 deg/sec	Better	About the Same	Better	FWB
	30 deg/sec	Much Better	About the Same	Much Better	FWB
D	All	Much Better	About the Same	Much Better	FWB

Figure 9: PIO Comparison Summary for Simulation

Aircraft Case	Rate Limit	FWB vs No-Filter	DS vs No-Filter	FWB vs DS	Best Performer
C	All	Better	About the Same	Better	FWB
	60 deg/sec	About the Same	Worse	Better	FWB
	45 deg/sec	Better	About the Same	Better	FWB
	30 deg/sec	Better	Worse	Better	FWB
	15 deg/sec	Better	About the Same	Better	FWB
D	All	Much Better	About the Same	Much Better	FWB

Figure 10: PIO Comparison Summary for Flight Test